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Interference into 13 cm EME bands from 2.4 GHz ISM band

Paul Chominski, WA6PY, 17433 Gibraltar Ct, San Diego, CA 92128, USA

Abstract

This paper presents measurement results of interference in unlicensed Industrial, Scientific and Medical - ISM 2.4 GHz band. Source and nature of those interferences are explained. This problem has been already recognized by the designers of equipment working in ISM band, but is not very well documented in literature. Computer communications systems use very sophisticated algorithms to avoid interference and collisions. Solutions to minimize impact of those interferences on receiving very low level continuous signal are proposed in this paper.

Introduction

Unlicensed ISM Frequency band extends from 2400 to 2484 MHz. This band is occupied by many different users. Most of the users use burst mode and frequency hopping or spread spectrum in order to minimize probability of collisions. Japanese EME band 2424 MHz is allocated inside ISM Band. 2304 and 2320 MHz bands are also affected by interferences in ISM band.
Additional spurious signals will be generated in nonlinear components as a result of intermodulation and cross modulation. LO phase noise and LO spurs of the transmitters and receiver will increase number and level of interfering signal mixed down into the IF frequency.

Among most common sources of interference are:

1. Microwave ovens
Frequency: 2445 +/- 40 MHz
Power inside the cavity 500 – 1000 W = 57 – 60 dBm
Radiated power depends on cavity (door) shielding and leakage through the power cord
Very unstable frequency sweeping across and even over the edges of the band.

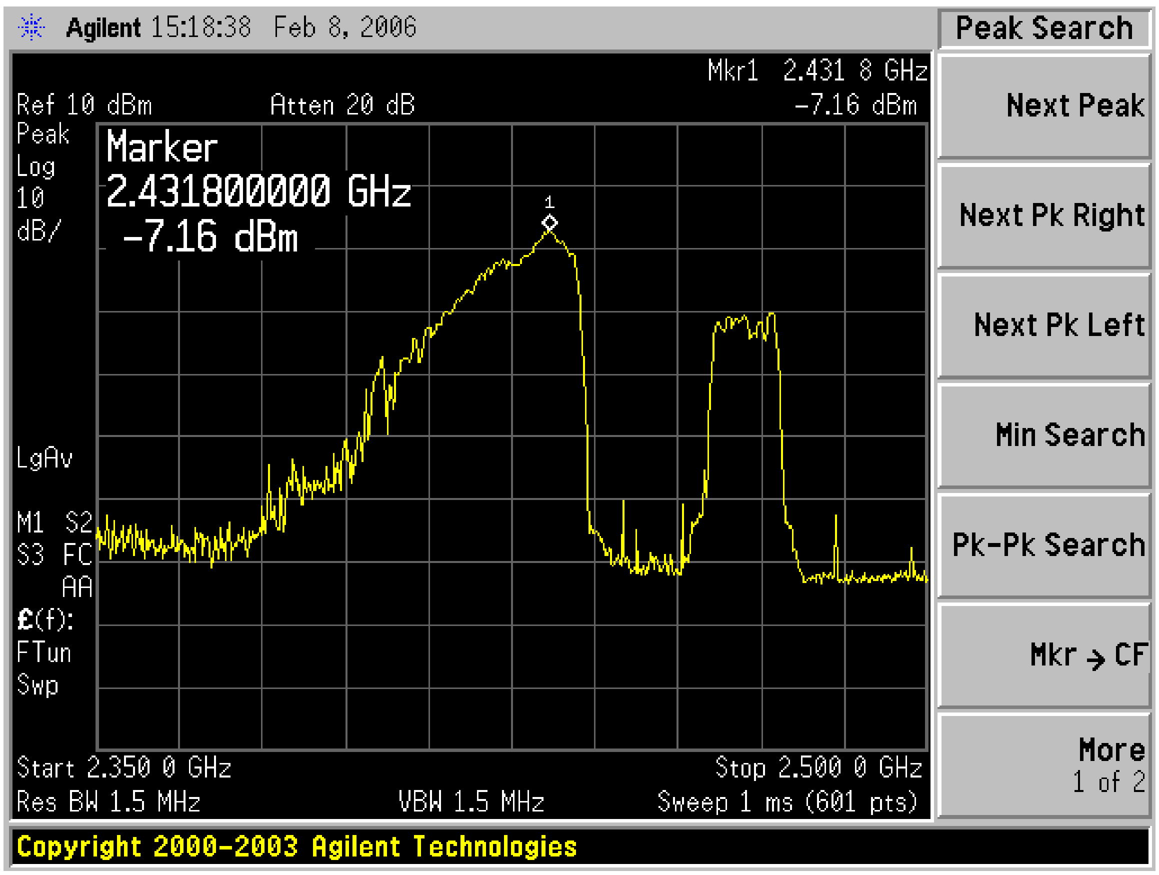
2. Wireless communication as Wireless LAN, 802.11 b,g, BlueTooth and wireless phones
Frequency: 2400 – 2484 MHz
Power: 0 to 30 dBm, EIRP 36 dBm max = 4W
Modulation FSK, GFSK, BPSK, QPSK 16 and 64 QAM, Frequency hopping or Spread Spectrum.
Occupied BW: from 30 kHz to 22 MHz
Bursts duration from 1 ms to 15 ms

3. Other interferers in IMS band for example toys, remote video cameras, scientific and medical equipment.

4. Interference from WCDMA (UMTS) band will create problems in 2304 and 2320 MHz bands due to not sufficient Image rejection and receiver LO phase noise.

Characteristic of the interfering signals

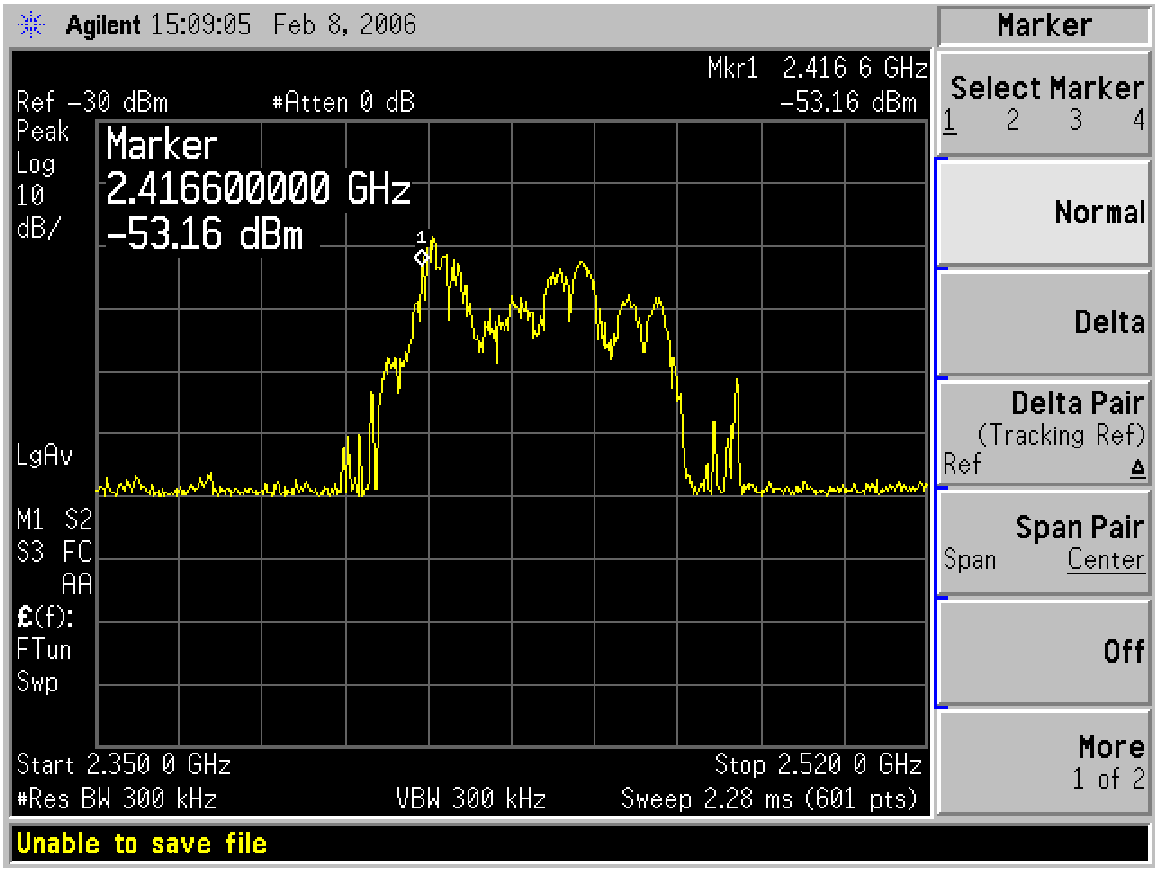
Spectrum of the interfering signals was measured with Agilent spectrum analyzer PSA E4440A and ¼ WL Ground Plane antenna.



Picture 1. Interference from Microwave Oven integrated over 1 minute

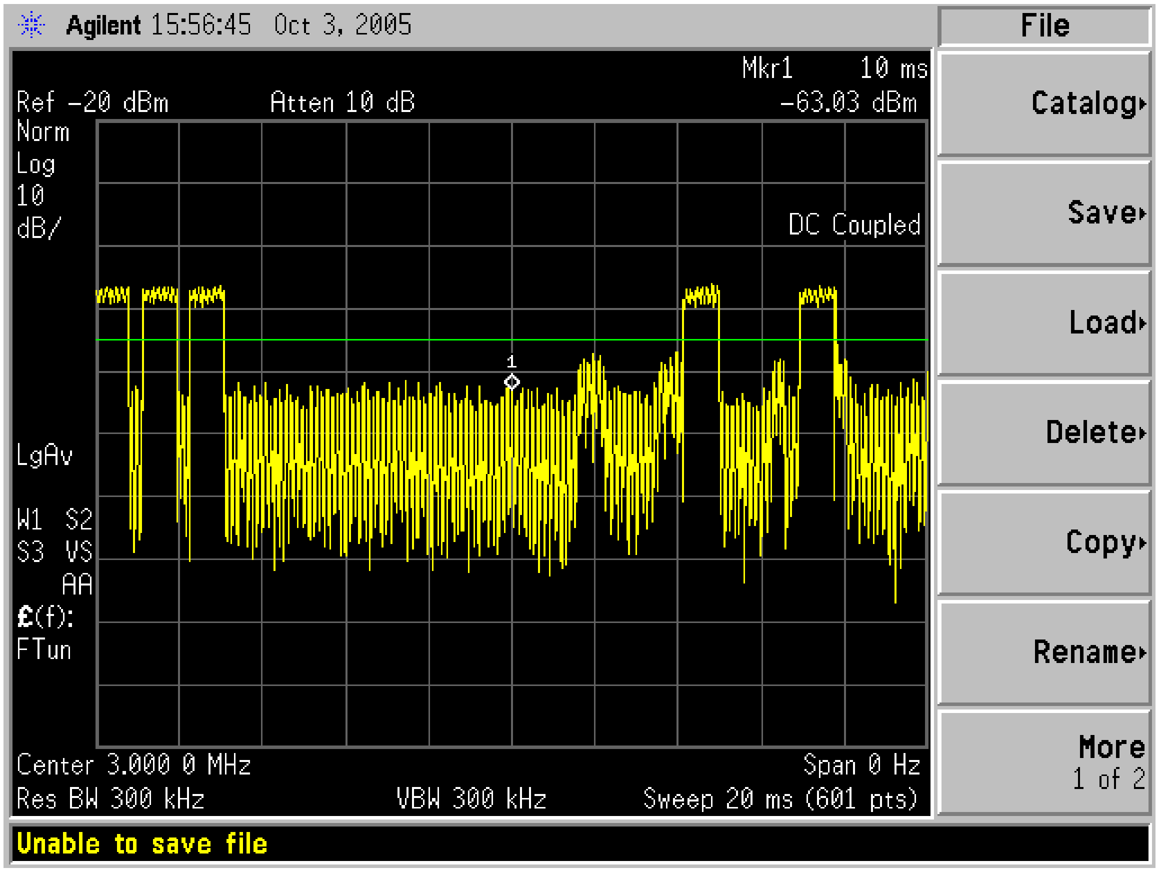
Radiation from microwave oven heating food was measured 1 m away. Generated up to -7.2 dBm and signal frequency is moving from 2395 to 2475 MHz depending on the position of food on the carousel.

Next picture shows signals in typical office environment measured with monopole ¼ WL antenna. Power from the antenna can be up to -50 dBm. After sampling signal in 30 seconds period of time entire band is covered by the signal.

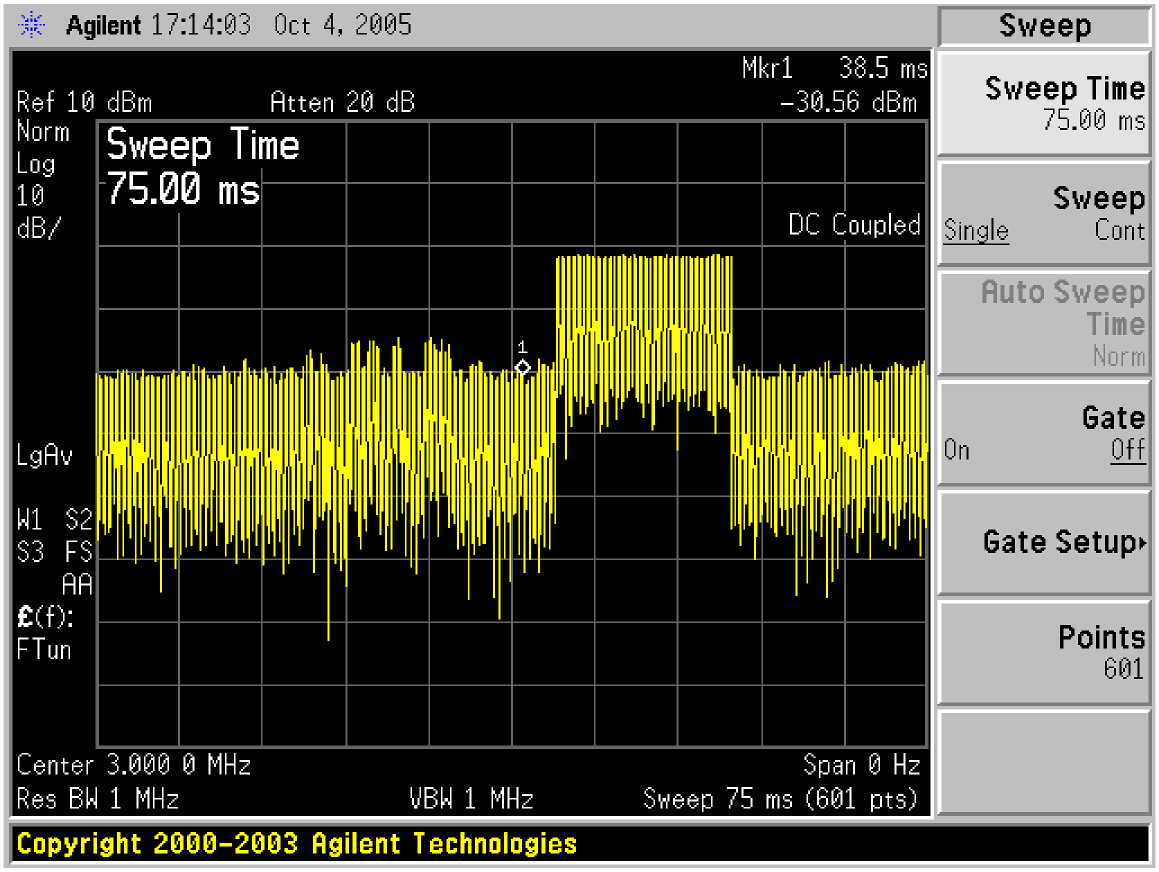


Picture 2. Interference from wireless communication in the office.

Following two measurements were captured also in the office at the output of Low IF receiver using high IP3 LNA and Image Rejection Mixer with Ground Plane ¼ WL antenna. Receiver was tuned to 2424 MHz and spectrum analyzer was set to zero span.



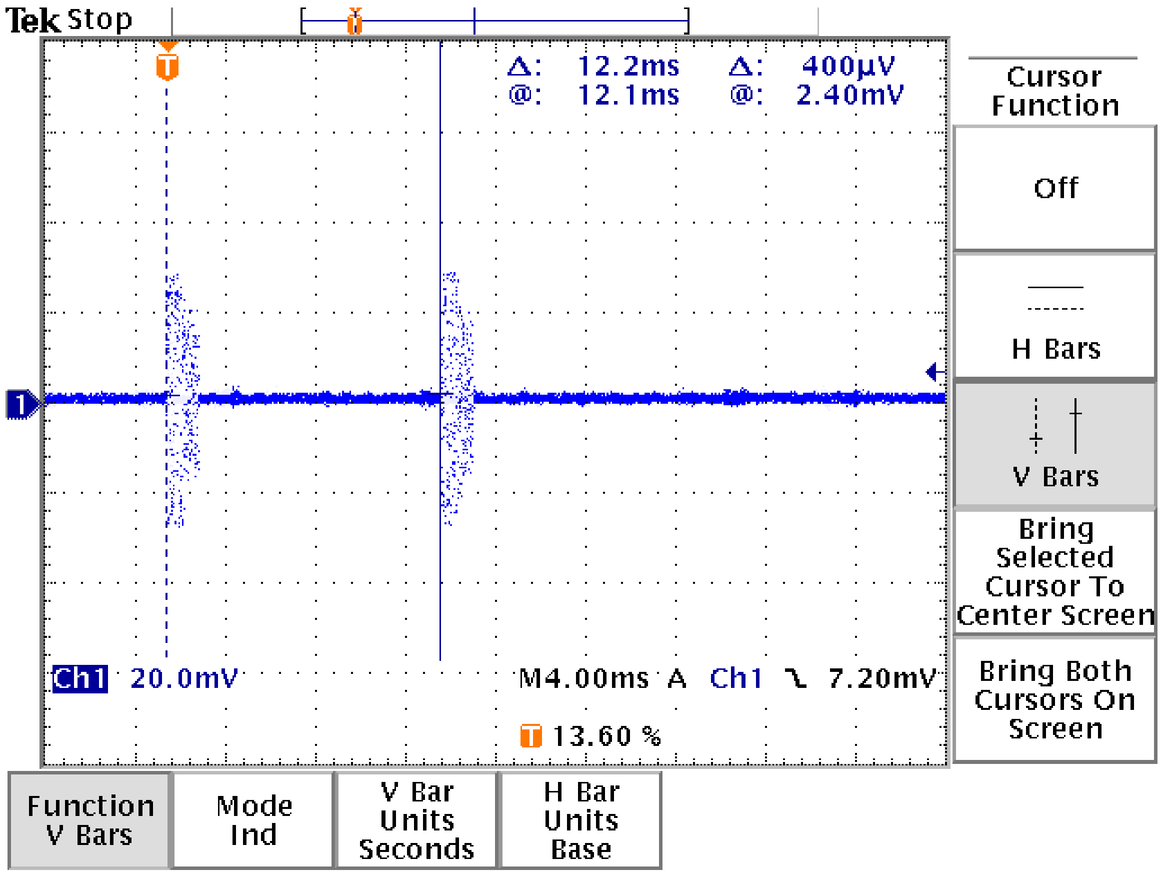
Picture 3. Three interference bursts have power -48 dBm/300 kHz, duration 1ms and repeated 200 us after each other. Next weaker burst comes 8ms later at 10 dB lower level. Next strong interference comes after 2ms.



Picture 4. 15 ms long burst of interference, power level -11 dBm/MHz = -16.2 dBm/300 kHz.

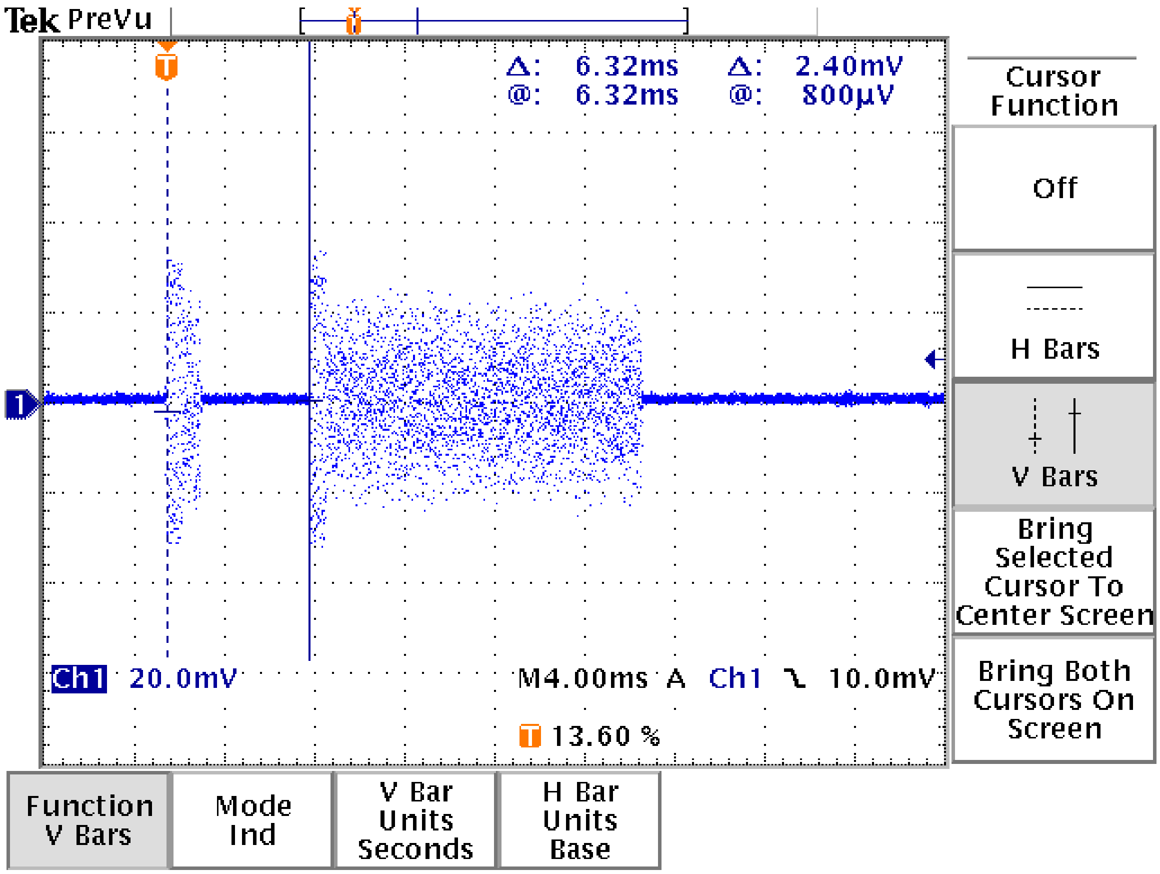
Next set of measurements was performed with my dish in residential area. Measurement antenna 3.6 m dish f/D = 0.36 fed with W2IMU feed horn. This antenna has high gain and low side lobes. Dish was pointed in direction of other houses at the distance 100 m with elevation 15 deg. LNA is connected directly to the feed horn. LNA gain is 40 dB followed by feeder cable, power splitters between three downconverters. 2424 MHz signal is downconverted first to 144 MHZ and secondly to 28 MHz.

2424 MHz signals were captured with Tektronix digital oscilloscope TDS 3014B 100 MHz 1.25 GS/s at the 28 MHz IF output.
Total gain between antenna and 28 MHz IF output is about 40 dB.



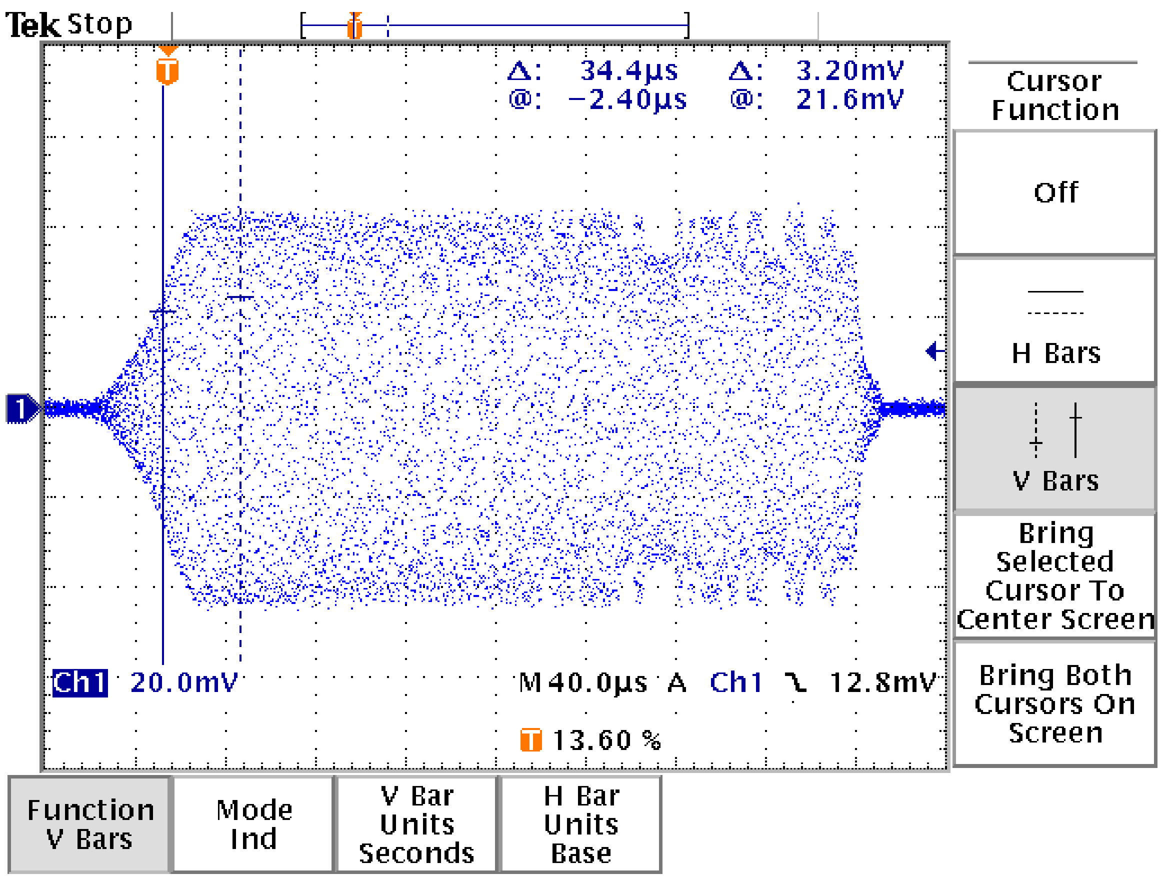
Picture 5. Time domain interference signals at 28 MHz IF output.

Amplitude 60 mVp-p corresponds to 21.3 mV rms at 50 ohm. Power -20.5 dBm.
This corresponds to the power from the antenna port about -60 dBm.
Burst duration 2 ms, spacing between bursts 12 ms.



Picture 6. Time domain interference signals at 28 MHz IF output.

First burst duration is 2 ms, second burst duration is 15 ms, spacing between bursts 6.3 ms.



Picture 7. Time domain interference signals at 28 MHz IF output.

Amplitude 88 mVp-p this corresponds to 31.2 mV rms at 50 ohm. Power -17 dBm

Noise temperature of this receiving system is about 100 K. Noise floor at 28 MHz IF is -118 dBm/100 Hz.

Minimizing interference from ISM band:

Interference problem can be divided between two categories:

1. In JA segment 2424 MHz – direct interfering signals and non-linear products
2. In 2304 and 2320 MHz bands – non linear products

In addition to direct interfering signals on received frequency, additional spurious signals will be generated in the receiver as nonlinear products and mixing products with LO phase noise and LO spurious.

Let’s consider two signals from ISM band which will generate IM3 product in 2424 MHz band.
Assuming power from the antenna = -60 dBm for each tone and total LNA gain is 45 dB.

For total noise floor at the LNA input -185 dBm/Hz, noise in 100 Hz receiver channel will be -165 dBm/100Hz.
At the LNA output interfering signal will have power -15 dBm and noise floor -120 dBm/100 Hz.
In order to maintain IM3 products at the noise floor level IP3 of the LNA must be 37.5 dBm. This requires P_1dB of LNA about 25 dBm = 316 mW. For such linearity requirement final stage of LNA must be biased about to1.5 W DC power.

Different way to minimize this source of interference is limiting spectrum creating intermodulation products.

Narrow Band Pass RF Filter

For common Front-End LNA stages my proposal is to split signal between two BPF as close after the first LNA stages as possible. Antenna signal will be split between two filters. First will cover frequency range 2304 to 2320 MHz and second for 2424 MHz. with minimum possible bandpass. We should be able to use narrow band filters with BW about 10 MHz. This architecture will significantly lower number of spurious products in 2304 to 2320 MHz band and limit interference due to the non-linarities in 2424 MHz band.

Using such architecture will relax linearity requirements for the receiver chain.
For illustration use the same signal levels as in the above example.
If we use narrow band BPF after LNA with 30 dB Gain, interferer power will be -30 dBm/tone. Noise floor will be -135 dBm/100 Hz and IP3 22.5 dBm. Now P_1dB for LNA stages in front of BPF will be 10.5 dBm = 11.2 mW.

Linearity requirements for minimizing interference in 2304 and 2320 MHz bands

Intermodulation products are generated as mixing product between two tones in 2400 – 2484 MHz band and can fall into the 2320 and 2304 MHz bands.

2320 MHz band is 80 MHz below ISM band. Two signals from two frequency ends of the ISM band will generate IM3 product in 2320 MHz band.

Example 1: F1 at 2401 MHz and F2 at 2482 MHz will generate IM3 product at 2320 MHz.
Assuming that IIP3 of the down converter is 0 dBm and interfering signals from LNA are -20 dBm each, IM3 will be -60 dBm. This corresponds to S9 + 13 dB.

2304 MHz band is 100 MHz below ISM band. Two signals from ISM band will generate IM5 product into 2304 MHz.

Example 2: F1 at 2404 MHz and F2 at 2454 MHz will generate IM5 product at 2304 MHz.

Assuming that IIP5 of the down converter is 8 dBm and interfering signals from LNA are -20 dBm each, IM3 will be -76 dBm. This corresponds to 3 dB below S9.

Cross modulation can also increase level of interference. Strong out off band amplitude modulatated signal with will modulate another signal in band of interest. QPSK, 16 and 64-QAM modulated signals have AM component and can generate cross modulation distortions.

Noise Blankers

Interference from ISM band has very high amplitude and relatively high repetition frequency up to 1 kHz.

Assuming RX system with Noise Temperature = 100 K, noise floor will be -178.5 dBm/Hz. For receiver BW = 100 Hz noise floor will be -158.5 dBm/100Hz. Interfering signals can have power -60 dBm.

Noise blanker gate should suppress interferer by 98.5 dB. Not all of the standard noise blankers have such high isolation.

Due to the high repetition frequency timing of the noise blanker is critical. Gate should switch off little before the pulse is beginning and do not keep gate in off state too long after end of interfering pulse.

Interference problems Due to LO Phase Noise

Typical LO phase noise of 802.11 and BlueTooth transmitters is:

-140 dBc/Hz at 10 MHz offset
-155 dBc/Hz at 100 MHz offset

For TX power 30 dBm in 2424 MHz   noise in 2304 band will be = -125 dBm/Hz

Following table shows noise floor increase due to the LO phase noise of ISM transmitter. TX power = 30 dBm, Path loss between TX and receiving antenna = 60 dB including gain of the antennas, RX system noise temperature = 100 K what corresponds to RX total NF = 1.29 dB.

Band MHz	Frequency Offset	Phase Noise dBm/Hz	Phase Noise at RX input	Effective Noise Temp	Effective RX NF
2424	10 MHz	-110	-170 dBm/Hz	715 K	1.59 dB
2320	100 MHz	-125	-185 dBm/Hz	22.9 K	5.81 dB

Cascading power from more such interfering signals increase noise floor.

Low noise temperature antennas

Low side and rear lobes antenna will also help to minimize level of interfering signals entering LNA. Important will be low spill over and low side and rear lobes feed horn.

Conclusions

Level and number of sources of interference in 2.4 GHz band is growing all the time. We can not improve noise or spurious already transmitted by external source. We can decrease number and level of the spurious signals generated in receivers by increasing linearity, using narrow band RF filters and lowering noise temperature of the antennas. Interfering bursts on the receive frequency can be suppressed by using well designed Noise Blankers.

References

FCC Rules for ISM Band Wireless Equipment www.fcc.gov